SKMP/PIL
C 786

LIBRARY

OCT 24 1985

National Marine Fisheries Service
2570 Dole Street
Honolulu, Hawaii

STATISTICAL CONSIDERATIONS IN THE DESIGN OF TRAWL SURVEYS

by

M.J. Fogarty
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Ma 02543
USA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, June 1985

PREPARATION OF THIS DOCUMENT

Two small workshops were held in July 1984 in the fisheries laboratories of Fano and Mazara del Vallo (Italy), with the collaboration of Dr. M.J. Fogarty of the Northeast Fisheries Center (Woods Hole, USA) in order to examine the trawl survey methodology used in the past in the Adriatic Sea and to offer a common theoretical background to all Italian laboratories which are going to be engaged from 1985 onwards in large-scale trawl surveys of all the Italian waters. Because of the multispecies nature of the resource, the area by area aspects of management in the Mediterranean, and the specific need to deal with length frequency analysis, the workshops carefully considered the problem of non-random distribution of the sampled magnitudes, the possibility of using systematic sampling and post-stratification, and the problem of defining confidence limits to length frequency distributions. Because of this particular emphasis and of its potential use beyond the Italian waters and the Mediterranean, and for tropical waters in general, it was felt that this informal report should be issued as a Fisheries Circular pending further elaboration which might lead to the preparation of a manual on trawl surveys in tropical regions.

Abstract

This paper is the report of two workshops organized jointly by the Laboratorio di biologia marina e pesca (Fano,Italy) and the Istituto di Tecnologia della pesca e del pescato (Mazara del Vallo, Italy) with the collaboration of the Northeast Fisheries Center (Woods Hole, USA). It briefly recalls the main statistical concepts of trawl surveys, but also offers considerations on systematic sampling, variance of length frequency distributions and post-stratification which are particularly useful in tropical regions.

Acknowledgements

The Secretariat of the General Fisheries Council for the Mediterranean and the Directors of the Fisheries Laboratories of Fano and Mazara del Vallo are grateful to the Northeast Fisheries Center (Woods Hole) of the US National Marine Fisheries Service (NMFS) for having accepted to send Dr. M.J. Fogarty as the main lecturer at the workshops.

W/R5030

For bibiliographic purposes this document should be cited as follows:

Fogarty, M.J., Statistical considerations in the design of trawl surveys.
1985 FAO Fish.Circ., (786):21 p.

FAO Fisheries Circular (FAO Fish.Circ.)

A vehicle for distribution of short or ephemeral notes, lists, etc., including provisional versions of documents to be issued later in other series.

CONTENTS

		Page
1.	INTRODUCTION	1
2.	SURVEY DESIGN	1
	2.1 Objectives	1
	2.2 Sampling Units	2
	2.3 Bias and Precision	2
3.	SIMPLE RANDOM SAMPLING	3
4.	STRATIFIED RANDOM SAMPLING	4
	4.1 Post-Stratification	6
5.	SYSTEMATIC SAMPLING	6
6.	STRATIFIED SYSTEMATIC SAMPLING	8
7.	BIOLOGICAL SAMPLES	9
8.	TRANSFORMATIONS	10
9.	APPLICATIONS FOR STOCK ASSESSMENT	11
10.	ADRIATIC SEA SURVEY	14
11.	REFERENCES	15
12.	TABLES	17
13.	FIGURES	18
14.	APPENDIX A	21

Digitized by the Internet Archive
in 2025

https://archive.org/details/fao-fisheries-and-aquaculture-circular_1985-06_786

1. INTRODUCTION

Research vessel trawl surveys play a central role in characterizing changes in the distribution and relative abundance of fish populations. The survey may be directed at a single species or a multispecies complex. Similarly, the objectives of the survey may be narrowly defined (for example, to measure the relative abundance of a particular species) or may encompass a broader range of objectives such as defining the size or age composition, sex ratio, stock composition, or other population characteristics of one or more species. The principal advantage of research vessel surveys relative to alternative methods is the rigorous standardization and degree of control which is possible. Since commercial fishing operations are invariably size and species selective, complete description of the population or populations of interest is seldom possible based on this source alone. Trawl surveys offer the additional advantage of nearly synoptic coverage of the area of interest.

A description of population fluctuations of species of commercial interest is of immediate concern for management purposes. Forecasting the abundance of the stock prior to the fishing season, for example, may be crucial in establishing quota allocations for the season. In other instances, detecting the influence of removals from the population by the fishery may be the principal objective. Providing a recruitment index is yet another example of the use of trawl survey results. The common theme in each of these applications is the need to characterize a set of attributes for one or more species which cannot be directly enumerated. The proper design, execution, and analytical treatment of a survey program is essential.

Aspects of the design of biological surveys with particular emphasis on trawl surveys have been documented by Abramson (1968), Grosslein (1969), Alverson (1971), Mackett (1973), Gulland (1975), Saville (1977), Ulltang (1977), Troadec (1980), Doubleday (1981), Grosslein and Laurec (1982), and Sissenwine *et al.* (1983). These sources provide an excellent overview of approaches to assessment of aquatic resources based on probability sampling programs. The present report is based on a series of lectures presented at the Instituto di Tecnologia della Pesca e del Pescato, Mazara del Vallo, Sicily during July 1984. The lectures were intended to introduce principles of sampling theory to aid in the development and design of a coastwide trawl survey to be implemented in Italy. An attempt has been made to make the report relatively self-contained since primary source materials may not be readily available. Nevertheless, the reader is urged to consult the original sources wherever possible. The material in this document summarizes information in texts on sampling theory by Cochran (1977), Sukhatme and Sukhatme (1970), Hansen *et al.* (1953), and Kish (1965). Additional emphasis has been placed on topics which are sometimes covered lightly in treatments of trawl survey design. For example, alternative systematic designs are described and the use of cluster sampling to evaluate population attributes is outlined. An attempt has been made to complement other treatments of this general topic. A brief evaluation of sampling designs used during surveys conducted in the northern Adriatic region by personnel of the Laboratorio di Biologia Marina e Pesca, Fano, Italy is also presented.

2. SURVEY DESIGN

2.1 Objectives

An easily overlooked but essential aspect of the design of any sampling program is a clear specification of the objectives of the survey. If the survey is to address multiple objectives, then a priority must be assigned to each. It may be difficult or impossible to design a survey which is optimal for all objectives simultaneously; accordingly, the design of the survey should reflect the sampling requirements for the objectives with the highest priority. For example, a possible hierarchy of objectives for a survey targeted at a singles species might be to (1) determine relative abundance (2) estimate size or age composition and (3) to determine sex ratios. It is possible that the first objective might be best attained with the one sampling design while an appropriate design for the others would require a different strategy entirely. Nevertheless, useful information for the other objectives might still be possible under the design specified for the primary objective. A hypothetical list of objectives for a trawl survey in priority order of importance is listed in Table 1.

It is necessary to specify the population to be sampled, the method of observation or mensuration, the fundamental sampling unit, and the degree of precision required. In defining the population to be sampled, it must be recognized that the Target population (the population we wish to describe) may not coincide with the Sampled population (the population we are actually able to measure). For instance, we may wish to measure the abundance of a certain species but find that the smallest individuals are not vulnerable to the sampling gear due to escapement or differing patterns of spatial distribution. It must be recognized that the entire population has not been characterized.

The choice of sampling gear will reflect a number of pragmatic requirements including efficiency, reliability and consistency of performance, cost of operation etc.. For trawl surveys, alternative net designs may be more or less efficient for certain species (for example, pelagic vs demersal species) and the choice of net type may be based on a list of priority species.

2.2 Sampling Units

Specification of the sampling units or the sampling frame is of course essential to the design of the survey. For the purposes of most trawl surveys where the primary objective is to estimate relative abundance, the sampling frame consists of units defined in two dimensional space throughout the area of interest. The area occupied by the species or species complex is divided into identical units and these provide the basis for selection of the sample. In practice, the sample unit will often be defined as an area sufficiently large to contain any trawl haul started at the center of the unit (Grosslein and Laurec 1982). The size of the sample unit is thus dependent on tow speed and duration. The area actually sampled is of course considerably smaller than the sampling unit defined in this way, leading to some ambiguity in defining the primary sampling unit (see following section). Areal expansion of the relative abundance estimates requires information on the area actually swept by the net (a technical problem in gear performance and dynamics) and factors affecting the catchability of the species including behavioural response to the gear.

2.3 Bias and Precision

It will be useful to specify the degree of precision required for the survey estimates. This may be essential for managers who use the information for policy decisions. Often the specification of the acceptable level of precision will in fact be determined by policy requirements. An important aspect of survey design will be to provide results at some fixed level of precision at minimum possible cost or, alternatively, to provide results of the highest possible precision for some fixed cost. It is useful to distinguish between precision and accuracy. An accurate estimate is one which is close to the true (parametric) population value. A precise estimate is one which is highly repeatable, that is, successive estimates are similar and do not vary greatly. Clearly, an estimate which is accurate need not be precise nor does the converse necessarily hold. The difference between the true population value of a parameter and the sample estimate is a measure of bias. Some of these concepts are summarized in Figure 1. The implications of bias in an estimator depend on the type of application. Bias may be of less consequence if the primary objective is to track changes in relative abundance over time but may be extremely important if a measure of absolute abundance is required.

It will almost invariably be useful to conduct a pre-survey prior to the start of operations to determine the level of variability likely to be encountered, aspects of spatial distribution which may be useful in determining stratum boundaries and to test operational procedures. Information of this type may also be available from prior studies conducted for other reasons or from alternative sources such as the commercial fishery. Centers of abundance for a particular species or an assemblage of species, for example, may be inferred from the spatial distribution of fishing effort if it is impractical to conduct a pre-survey due to time or cost constraints.

3. SIMPLE RANDOM SAMPLING

Although it is almost always possible to specify a sampling design which will yield more precise estimates than simple random sampling (SRS), this topic provides a convenient introduction to sampling designs in general. If no prior information is available on the distribution and relative abundance of the species of interest, it may be useful to conduct a pre-survey based on a simple random sampling design or a systematic sample (to be discussed further in a later section).

The area to be surveyed is divided into N non-overlapping units of equal size and a sample of size (n) is chosen. Each sample has an equal probability of being chosen. The population mean is given by:

$$\bar{y} = \Sigma y_i/n \qquad (1)$$

where y is the variable of interest (e.g. fish density). An unbiased estimator of the population variance is:

$$s^2 = \Sigma(y_i-\bar{y})^2/(n-1) \qquad (2)$$

An unbiased estimator of the variance of the mean is:

$$v(\bar{y}) = \frac{N-n}{N} \frac{s^2}{n} \qquad (3)$$

where the first term is the finite population correction (FPC). In general, the FPC may be ignored if it is less than 0.01 (Cochran, 1977). As noted previously, there is often a discrepancy between the number of units in the sample frame and the number of trawl hauls which could hypothetically be placed in the survey area. The area covered in an actual haul is small relative to the survey area and for this reason, the FPC is often ignored in subsequent computations. In this report, the interpretation of N will be the number of possible trawl stations in the area to be surveyed.

A computational formula for the variance which is considerably easier to use is given by:

$$s^2 = \frac{1}{n-1} [\Sigma y_i^2 - (\Sigma y_i)^2/n] \qquad (4)$$

The standard error of the estimate is of course given by the square root of the variance of the mean (Eq. 3) and confidence intervals for the estimate of the mean are:

$$\bar{y} \pm [(N-n)/N]^{\frac{1}{2}} \cdot t \cdot s/n^{\frac{1}{2}} \qquad (5)$$

where (t) is a multiplier and all other terms are defined as before. For small sample sizes (say $n < 30$), the multiplier (t) should be taken from a t-distribution with n-1 degrees of freedom and at some specified probability level. For example, for a sample size of 20 and at the 95% probability level, $t = 2.093$. For large sample sizes, the t-distribution converges to a Normal distribution. If we construct a 95% confidence interval, we state that the interval contains the true parametric value with a probability of 0.95.

It is useful to note that in constructing confidence intervals for large sample sizes we assume that the estimates are drawn from a Normal distribution (by the Central limit theorem) but make no assumptions about the underlying distribution of the variate itself. Sample means drawn from underlying Normal distribution are always normally distributed while the distribution of sample means drawn from a skewed population approaches normality as sample size increases. Trawl survey data may be highly skewed due to the contagious distribution pattern of many fish populations. It may therefore be helpful to transform sample data taken from a non-normal population if sample sizes are small. The topic of transformations is treated in more detail in a later section of this report.

If our objective is to provide a measure of absolute abundance, then information on the fra tion of the population actually vulnerable to the trawl is necessary. This fraction, the survey catchability coefficient (q), is a complex function of the behavior both of the gear and the species sought. Clark and Brown (1977) calculated survey catchability coefficients by taking the ratio of survey catch to population size estimates determined by Virtual Population Analysis or any suitable alternative method. The survey catch (y) is related to the population abundance (Y) by the relationship y=qY where q is the survey catchability coefficient (Edwards, 1968). Note that for simplicity, catchability is here assumed to be constant, a condition which will not strictly be true. The population total is given by:

$$Y = \frac{N}{q} \Sigma y_i / n \qquad (6)$$

and the variance of the population total is:

$$v(Y) = \frac{N^2 s^2}{q^2 n} \qquad (7)$$

If the catchability coefficient varies among size or age classes, it may be necessary to treat these classes separately. If the catchability coefficient is unkown, then q is typically set to 1.0. It must be recognized, however, that the gear is not completely efficient and that expanded population size estimates will underestimate true population values unless an adjustment for vulnerability to the gear is made. If the catchability coefficient is not a constant but rather a random variable itself, the expression for the variance of the mean is considerably more complex than Eq. (7). Since information on the nature of variability of the catchability coefficient will seldom be available, adjustment for variable catchability will not be further addressed in this paper.

In the following sections, the finite population correction will not be specified since the typical approach in trawl survey applications is to consider the area swept by the net to be the primary sampling unit and therefore the number of possible sampling units is large. Nevertheless, it should be noted that the FPC will be required under some circumstances and the term ((N-n)/NJ should be added when sampling fractions are high.

4. STRATIFIED RANDOM SAMPLING

It will often be the case that some information of fish distribution will be available. Detailed biological studies may have been made to document habitat preferences related to substrate type, temperature, depth, or other factors. Alternatively, the commercial fishery may be viewed as a source of information since the fleet will invariably concentrate in areas of high abundance. This information may provide the basis for the determination of stratum boundaries.

The area to be sampled is subdivided into regions (strata) which are relatively homogeneous with respect to fish density. If stratum boundaries are correctly chosen, the variance within each stratum will be considerably lower than the variance obtained under simple random sampling, resulting in more precise estimates. Stratification also tends to result in a more equitable distribution of samples throughout the survey area, reducing the probability that large areas will remain unsampled. The most reliable basis for stratification in a trawl survey is of course prior knowledge of the distribution and abundance of the species sought prior to the start of the survey. If such information is not available, a correlated variable is often used as the stratification factor. For example, depth is often an important factor in the zoogeographic distribution of fish and since detailed bathymetric charts are available for many areas, depth often serves as the basis for stratification.

Following selection of the strata, a random sample is drawn independently within each stratum. An unbiased, consistent estimator of the sample mean of a stratified population is:

$$\bar{y}_{st} = \frac{1}{N} \Sigma N_h \, y_h / n_h \qquad (8)$$

where N is the total number of possible samples, N_h is the number of possible stations in stratum (h), and y_h is the mean of variable y in stratum (h). The variance of the sample mean is given by:

$$v(\bar{y}_{st}) = \frac{1}{N^2} \Sigma N_h^2 s_h^2/n_h \quad (9)$$

where s_h^2 is the sample variance in stratum (h). If the number of samples taken in each stratum is proportional to the stratum area (or the number of total possible stations in each stratum), we have a proportional allocation scheme and the samples are self weighting. Note that the results have been expressed in terms of the number of possible sample units (N) and the number of samples taken (n) rather than area, however, the size of each sampling unit is identical and therefore weighting factors could have been expressed in terms of area.

Confidence intervals are constructed as for simple random sampling after the appropriate weighting factors have been applied. If the sample sizes within each stratum are relatively small, the t-distribution should be used. An approximate formula for the degrees of freedom is given by Cochran (1977).

An estimator for the population total under stratified random sampling is given by:

$$Y_{st} = \Sigma \frac{N_h}{q_h} \bar{y}_{st} \quad (10)$$

where N_h is the total number of possible samples in stratum (h) and q_h is the catchability coefficient in stratum (h). Catchability is expected to change with substratum type since the gear will not be equally efficient on all bottom types and therefore it will be useful to define strata in terms of substrate type, if possible. If we assume a constant catchability over all strata, then the catchability term may be taken outside the summation. The variance of Y_{st} is:

$$v(Y_{st}) = \Sigma \frac{N_h^2}{q_h^2} s_h^2/n \quad (11)$$

Although proportional allocation schemes are often employed in trawl survey sampling programs, alternative allocation methods may be more desirable. For example, an optimal allocation scheme may be established based on the following criteria. Let

$$\frac{n_h}{n} = (N_h s_h/c_h^{\frac{1}{2}}) / \Sigma(N_h s_h/c^{\frac{1}{2}}) \quad (12)$$

where c_h is the cost of obtaining a sample in stratum (h) and all other variables are defined as before. To minimize the variance for a fixed cost (C), the total number of samples is given by:

$$n = \frac{(C-c_o)\Sigma N_h s_h/c_h^{\frac{1}{2}}}{\Sigma(N_h s_h c_h^{\frac{1}{2}})} \quad (13)$$

where c_o is a fixed cost independent of the allocation of the samples (e.g. overhead costs for running the vessel). To minimize cost for a fixed level of variance (V), we have:

$$n = \frac{(\Sigma \frac{N_h}{N} s_h c_h^{\frac{1}{2}}) \Sigma \frac{N_h}{N} s_h/c_h^{\frac{1}{2}}}{V + (1/N)\Sigma(N_h/N)s_h^2} \quad (14)$$

Thus, depending on whether fixed cost or fixed variance is viewed as the constraint, the total sample size is determined by Eq. (13) or Eq. (14) and the result is substituted into Eq. (12) to determine the sample size for stratum (h). Note that application of these methods requires advance information on the variance and cost factors involved. A pre-survey may be used to obtain information on variance levels or the results of prior surveys may provide a useful indication of expected levels of variability if the variances are relatively stable over time. In general, there will often be a positive relationship between the mean and variance for species obtained in trawl surveys (e.g. Sissenwine et al. 1983) and it will therefore be useful to consider allocating more samples in strata where abundance is high rather than employing a strict proportional allocation scheme.

4.1 Post-Stratification

If sufficient information to allow stratefication is unavailable prior to sampling, gains in precision are still possible by post-stratifying the sample (Cochran, 1977). It must be possible to determine the stratum weights for the newly defined strata and we must have at least two samples in each of the post-strata. If these conditions are met, the estimate of the mean is:

$$\bar{y}_{pst} = \Sigma \frac{N_h}{N} \bar{y}_h \qquad (15)$$

where y_h is the post-stratified mean. The variance of y_{pst} is:

$$v(\bar{y}_{pst}) = \frac{1}{n} \Sigma \frac{N_h}{N} s_h^2 + \frac{1}{n^2} \Sigma (1 - \frac{N_h}{N}) s_h^2 \qquad (16)$$

Often, it will be possible to considerably increase the precision of an estimator by post-stratification. This will be particularly true in multispecies surveys where it is difficult or impossible to design a survey which is appropriate for all species.

5. SYSTEMATIC SAMPLING

A systematic sampling design is one in which samples are taken in some fixed pattern. Due to the relative simplicity in designing and executing such a sampling program, systematic sampling has been extensively employed in biological surveys. In addition, a systematic design has the intuitive appeal that uniform coverage of a broad area is possible. This may be particularly advantageous if little a priori knowledge is available on the distribution and relative abundance of the species sought. A systematic survey may therefore be considered as a useful design for a pre-survey in which the principal objective is to gain basic information for the design of subsequent work. In contrast, a simple sample used for this same purpose may suffer from the disadvantage of uneven coverage of the survey area and some centers of abundance may be missed.

Systematic sampling designs unfortunately do not permit simple estimates of variance except under certain assumptions about the distribution of the population or unless additional information is available. Nevertheless, there are certain conditions under which systematic samples may yield more precise estimates than either simple random sampling or stratified random sampling. In surveys designed to meet multiple objectives, it may not be possible to specify an optimal stratified design and a systematic sample may be the best compromise. Although it is almost always true that stratified random sampling is more precise than simple random sampling, no comparable statements can be made about the relative precision of systematic sampling vs stratified random sampling which hold under all conditions. The distribution of the population and in particular, the degree of aggregation (spatial autocorrelation) determines which design is preferable. This topic is explored further in this section, however, some basic concepts are introduced first.

There are several approaches to designing a systematic sampling program in two dimensions, resulting in either a regular (aligned) or an unaligned pattern. The starting points should be randomized although this aspect of systematic sampling is unfortunately often overlooked. To illustrate these approaches with a simple example, suppose we have an area which is subdivided into 16 sections (Figure 2) and we wish to take a single sample in each. In a sense, we have created 16 strata of identical size. Considered in this way, the difficulty in estimating the variance of a systematic sample becomes immediately clear since we are taking only one sample in each "stratum". If each section is further subdivided, we can choose a random starting point for one section (for example, the upper left corner) by selecting a pair of random numbers which define the row and column of the subsection to be chosen. Each sample then occupies the sample relative position in each of the remaining sections (Figure 2), resulting in a regular or aligned grid pattern.

Alternatively, suppose we choose a random start position for the upper left corner as before. We now choose by random numbers, the position of subsequent samples in the horizontal direction for the first column. Thus for the first column, all samples occupy the sample relative position in the vertical direction but differing possitions in the horizontal direction (Figure 2). We now choose by random

numbers the vertical coordinates of the samples in the remaining cells of the first row (maintaining the same relative horizontal position as in the upper left corner cell). The position of samples in all other cells is then determined by placing each subsequent sample at a distance d (equal to the length of a side of each section) apart (Figure 2). This unaligned sample gives the appearance of a random sample at first glance but the regularity in the sampling design is still apparent. Although this method of sample selection may seem to be awkward relative to the aligned sample method or to random sampling, it has been shown that such a design is often superior to all other possible designs (Quenouille 1949, Das 1950, Bellhouse 1977).

The mean of a systematic sample is calculated in the usual way, however, caution is required if the population follows a trend - for example, a linear gradient in abundance or a periodic trend. If a linear trend is evident, the simplest approach is to take a centrally located sample in each section or unit of the sample grid. Linear gradients may occur if we are sampling along the main axis of an estuary or from shallow to deeper water etc.. Periodic trends in abundance or density may be relatively rare, however, periodic trends in vulnerability or catchability may occur and may affect abundance estimates. For example, there may be diurnal changes in catchability associated with changes in fish behavior at different light levels or tidal phases. It is extremely important to be aware of trends in population abundance or vulnerability when conducting a systematic survey to avoid bias in survey estimates. Again, the importance of eliminating bias differs depending on the objectives of the survey. If we require an index of relative abundance to monitor population trends rather than an estimate of absolute abundance, the effect of bias in our estimator will be less important. Nevertheless, the investigator should always be cognizant of the many potential sources of bias in the survey.

If the population is randomly distributed, it has been shown that the systematic sample can be treated as if it were a simple random sample and the means and variances calculated in the usual way (Cochran, 1977). One simple approach to determining if the population is in fact randomly distributed is to calculate the ratio of the variance to the mean (Pielou, 1977). The variance to mean ratio is equal to one for a randomly distributed population. If we take the Poisson distribution as a model for a random process, we note that this distribution is characterized by a single parameter (i.e. the mean and variance are identical) and we therefore expect a variance to mean ratio of 1.0. The expression

$$s^2(n-1)/\bar{x} \qquad (17)$$

is distributed as a Chi-Square variate with n-1 degrees of freedom (Pielou, 1977), providing a test statistic for the hypothesis of a random distribution. Much more detailed tests for spatial autocorrelation are available and could be applied to the problem of testing for randomness (Pielou, 1977).

Unfortunately, it will often be the case that the assumption of a random distribution will be rejected since experience with distribution patterns of many fish populations indicates that an aggregated or contagious distribution pattern is typical (i.e. the variance is greater than the mean) and we cannot apply results from random sampling theory.

An alternative is to design a systematic survey with multiple random starts. Essentially, we set up several (at least two) independent systematic samples in the area of concern. For an aligned sample, this would require selecting one random start point and then setting up the sample grid as described previously. Next, at least one more random start point is chosen and another sample grid is defined. We now have at least two samples in each section and it is possible to calculate the variance in each. Presumably, if we are operating under cost or time constraints, we may have had to use a larger grid size than if we had designed the survey without consideration of taking multiple samples.

If the fish distribution is homogeneous in each section, a simpler ad hoc approach is to take replicate samples at each station. Care must be taken that the additional sample(s) at each station are not affected by the earlier samples through depletion (sampling without replacement in a finite population) or by inducing changes in the behavior or distribution of fish in the immediate area. If these conditions are met, the additional sample(s) at each site provide an estimate of measurement error in the sampling process. It should also be noted that if we take replicate samples at a station

sequentially in time, then any diurnal factors which influence vulnerability will affect the results. If the distribution of fish in each 'stratum' or unit is not homogeneous, then the strategy of multiple random start is required. It is probable that under most conditions, the multiple random start design will be preferable.

It is possible to derive an expression for the variance of a systematic sample in terms of the intra-sample correlation. For simplicity, consider first sampling in one dimension only. Following Cochran (1977), we divide the population into k large units, each of which contains n of the original units (that is, we now have k separate systematic samples). The entire population is composed of N=nk units. An expression for the variance of the mean of a systematic sample is (Cochran, 1977):

$$v(\bar{y}_{sys}) = \frac{S^2}{n} \frac{(N-1)}{N} [1 + (n-1)\rho_w] \qquad (18)$$

where S^2 is the population variance and p_w is the correlation coefficient for pairs of samples within the same systematic sample. Note that because these results are expressed in terms of the population variance, we cannot use this expression to compute the variance of the mean based on sample data - our objective here is simply to provide an expression which permits a comparison of systematic and simple random sampling. The correlation coefficient is given by the following expression:

$$\rho_w = \frac{2}{(n-1)(N-1)S^2} \Sigma \Sigma (y_{ij}-\bar{y})(y_{iu}-\bar{y}) \qquad (19)$$

where y is the population mean. Although this expression may at first seem unfamiliar, note that the expression to be summed is simply a covariance term. Since any correlation coefficient is essentially the ratio between a covariance term and the product of the standard deviations of the variates (in this case replaced by the variance under simple random sampling the relationship between Eq. (18) and a correlation coefficient is clear. If the correlation coefficient is not significantly different from zero, then the distribution of the population is random and it is readily seen that the expression for the variance is equivalent to that for simple random sampling. It is also evident that any positive correlation among sample unit results in a higher variance. If there is a negative correlation, systematic sampling will have a smaller variance than simple random sampling sample relative to the size and degree of contagion of population aggregates will determine whether correlations among sample units will be detected. It is therefore not possible to state whether systematic sampling will be more or less precise than random sampling without further information on the distribution of the population and the spacing of sample units. It is clear however that systematic samples which are heterogeneous will be more precise than random samples.

Extension of these results from the one-dimensional to the two-dimensional case (sampling in a plane) is complex. Results have been summarized by Quenouille (1949), Das (1950), and Bellhouse (1977), based on various assumptions about the form of the autocorrelation function between samples (a measure of the aggregation of the population). The relative advantages and disadvantages of systematic vs random sampling designs depend critically on the form of the autocorrelation function and the spacing of samples and no general result can be stated which holds under all conditions. It can be stated that systematic sample designs are often as precise or more precise than random sampling. Cochran (1977) cites numerous cases in surveys of natural systems where systematic sampling provided more precise estimates than random sampling. Lenarz and Adams (1980) reported that systematic sampling was more precise than stratified random sampling in surveys for rockfish in the Northeastern Pacific.

6. STRATIFIED SYSTEMATIC SAMPLING

The advantages of stratification can also be applied to systematic sampling. If a basis for stratification exists, an independent systematic sample can be taken within each stratum; weighting factors are based on the area or number of sampling units as in stratified random sampling. If strata are chosen appropriately, the assumption of a random distribution within strata may not be unreasonable and the variance may be calculated as in SRS. The assumption of randomness should however be tested as described above for each stratum.

7. BIOLOGICAL SAMPLES

The sampling designs described to this point are appropriate for estimating density or relative abundance. However, we often need to characterize attributes of individuals within the population (e.g. the proportion of females, the fraction within some size or age category, incidence of parasitic infestation etc.). To determine the abundance of a population, we specified a sampling design which was defined in terms of spatial co-ordinates. Samples were not directly chosen with respect to individuals in the population. It is, of course, not possible to construct a sample frame of individual fish and specify a sampling design based on this frame. Instead, we take a cluster sample of individual fish obtained under the areal sampling design. The size of the cluster (number of fish obtained at each station) will of course vary. Each trawl haul is considered to be a primary unit and the individual fish obtained in a tow are considered to be the elementary units. In this case, the primary units are chosen with respect to spatial coordinates according to a random or systematic design. If all of the elementary units (individual fish) are examined for the attribute(s) of interest, the design is a single stage sampling design. If however a subsample of the elementary units is taken, we have a two stage sampling design. If still further subsamples are taken, we have a multistage sampling design. For example, from a given trawl haul, we might select a random subsample to determine length composition and from these individual fish select a random or stratified random subsample for age determination in a three stage design.

The importance of obtaining reliable information on the length or age composition of the catch in a trawl survey may, under certain circumstances, be considered as important as obtaining relative abundance data. This will be particularly true where it is difficult or impossible to obtain samples from the commercial fishery and yet information on growth and mortality rates is still required to guide policy decisions. Considerable attention has been devoted recently to developing estimators based on the length composition of the catch rather than on age composition for use in situations where age determination is not feasible (e.g. Pauly, 1979). Accordingly, it will be useful to consider methods of sampling the size composition of the catch in trawl surveys and obtaining useful estimators.

To provide an example of the use of cluster sampling to estimate the proportion of fish which fall in a given length category, consider a sampling design in which the stations have been selected by simple random sampling and that the entire catch is measured. It will invariably be the case that the number of fish obtained at each station will differ and this introduces some complications since the cluster size is a random variable. If cluster sizes are equal, then unbiased estimators of the mean and variance are possible (see Cochran, 1977). One approach to estimating the mean and variance when the cluster sizes are unequal is to use a ratio estimator. Assume that the proportion of fish in each size class follows a multinomial distribution. The proportion of fish in the jth size class is:

$$P_j = \Sigma a_i / \Sigma m_i \qquad (20)$$

where a_i is the number of individuals in this class in the ith cluster and m_i is the number of individuals in this cluster. The variance of P_j may then be estimated by:

$$v(P_j) = \frac{N^*-n}{N\ \bar{M}^{*2}} \quad \frac{(a_i - pm_i)^2}{n-1} \qquad (21)$$

In general, the estimates of the mean and variance are not unbiased; however, the bias should be negligible for large sample sizes.

An estimator for the population total at length j is:

$$N_j = N^* P_j \qquad (22)$$

and its variance may be expressed:

$$v(N_j) = \frac{N^{*2}}{n}\ v(P_j) \qquad (23)$$

If the primary sampling units have been chosen by a stratified random design, the analysis may proceed in much the same way as before with the appropriate weighting factors applied to the within stratum mean and variance.

It will sometimes be the case that the entire catch cannot be measured and a subsample must be taken. If the subsamples are of equal size, then the estimators are:

$$\bar{P}_{ij} = \Sigma P_j/n \qquad (24)$$

where $p_j=a_{ij}/m$ (i.e. the proportion of fish in category (j) in the ith subsample. The variance of p_j is given by:

$$v(P_j) = \frac{1-f_1}{n(n-1)} \Sigma(P_j-\bar{P})^2 + \frac{f_1(1-f_2)}{n^2(m-1)} \Sigma P_j(1-P_j) \qquad (25)$$

where f_1 is the sampling fraction in the first stage and f_2 is the sampling fraction in the second stage. Note that the terms (1-f) are finite population corrections and can be ignored if the sampling fractions are small.

It will often be the case that the sampling units will not be of the same size, particularly for the first stage as mentioned previously. In this case, weighting factors must be applied to allow for the differences in sample sizes as in Eq. (20).

It should also be noted that the estimators are no longer unbiased. Cochran (1977; Ch.11) presents results for subsampling with different sized sub-units.

In principle, it is possible to determine optimum allocation schemes for length composition in much the same way as for abundance estimates. There are however several differences which make development of an optimal allocation scheme for length composition more difficult than that for abundance estimates. The fraction of individuals is likely to change dramatically over time as recruitment and mortality rates change. Changes in the variance of proportion-at-age will be marked as the fraction within the interval changes from relatively rare or abundant (less than 20% or greater than 80%) to intermediate levels. Therefore, the advance estimates of variance required to specify an optimal design cannot necessarily be based on the previous year's data and a pre-survey would almost certainly be required. Further, an optimal design for a given length category may not be optimal for other size classes. Indeed, it is quite unlikely that a single optimum design could be specified.

If we require an estimate of the mean length of the population rather than the proportion at a given length interval, we define the ratio estimator:

$$\bar{\ell} = \Sigma \Sigma \ell_{ik}/\Sigma m_i \qquad (26)$$

where l_{ik} is the length of the kth individual in the ith sample. The variance of l is given by:

$$v(\ell) = \frac{N-n}{Nn\bar{M}^{*2}} \Sigma(\ell_{ik}-\ell m_i)^2/(n-1) \qquad (27)$$

Note that again, these estimators are not unbiased if the sample size varies among clusters.

8. TRANSFORMATIONS

The theory of sampling is not dependent on specific assumptions about the distribution of the population being sampled. Often, samples from biological populations are highly skewed. By the Central Limit Theorem, the distribution of the mean taken from repeated samples from even highly skewed populations will approach Normality as sample size increases (assuming finite variance). The construction of confidence intervals and significance tests do make assumptions about the distribution of the estimates. For some applications, further assumptions must be met (e.g. the mean and variance must be independent, etc.). Since it is often impractical to increase sample sizes to the extent necessary under the Central Limit Theorem, a common practice is to transform the variables prior to analysis. A distribution which has been extensively used as the basis for transformations to model the dispersion patterns of aquatic organismes is the negative binomial (see Pielou, 1969, Elliot, 1970). Taylor (1953) provided an early example of application of the nega-

tive binomial to trawl survey data. The probability of obtaining x individuals in a sample is:

$$P(x) = (1+\bar{x}/k)^{-k}\left[\frac{(k+x-1)!}{x!\,(k-1)!}\right] \cdot \left[\bar{x}/(\bar{x}+k)\right]^{x} \qquad (28)$$

where x is the sample mean and the exponent k is a parameter. To estimate the parameter k, an iterative procedure is necessary. An initial estimate may be obtained by:

$$k = \bar{x}^{2}/(s^{2}-\bar{x}) \qquad (29)$$

where s is the sample variance. This estimate of k may then be used as a trial value in the maximum likelihood estimator:

$$n \log_{e}(1+\bar{x}/k) = \Sigma \frac{A(x)}{(k+x)} \qquad (30)$$

where n is sample size, A(x) is the total number of counts greater than x. Trial values of k are substituted into Eq. (29) until both sides balance. Elliot (1970) provides a simple example of the calculations. The choice of an appropriate transformation depends on the value of k. Elliot (1970) recommends that if k is greater than 5, the inverse hyperbolic sine transform should be used:

$$\sinh^{-1}\left[\frac{x+0.375}{k-2(0.375)}\right]^{\frac{1}{2}} \qquad (31)$$

If k falls between 2 and 5, the appropriate transform is log(x+k/2).

A transform which is generally useful when the variance exceeds the mean (i.e. for a contagious distribution) is the log(x+c) transform (where c is a constant, usually taken to be 1.0). This will also tend to eliminate any dependence between the variance and mean. Often, the species of interest will not be represented in all trawl hauls (i.e. there will be zero counts). This of course is the rationale for adding a constant to the estimate before taking logarithms. The logarithmic transform will often effectively normalize the non-zero values, however, the distribution will still not be normal due to the effect of the zero catches. To remedy this problem, Pennington (1983) described a technique which explicitly considers the proportion of zero catches. An unbiased estimator of the mean is:

$$c = \frac{m}{n} \exp\left[\bar{y}\, G_{m}(\tfrac{1}{2}\, s^{2})\right] \qquad (32)$$

where m is the number of non-zero catches, n is the total number of hauls, and y and s^2 are the mean and variance of the non-zero catches respectively. The term G_m is a somewhat complicated function and it is described in Appendix with a computer algorithm for estimation. The variance of the mean is given by:

$$v(c) = \frac{m}{n} \exp\left[(2\bar{y})\left(\frac{m}{n} G_{m}^{2}(\tfrac{1}{2}\, s^{2}) - \frac{m-1}{n-1} G_{m}\left(\frac{m-2}{m-1}\, s^{2}\right)\right)\right] \qquad (33) \quad \text{for } m>1$$

If there is only one non-zero haul (m=1) the mean is estimated by V(c) =x/n.

If we are dealing with proportions (as in estimating the fraction within a given length interval), it may be helpful to apply the arcsin square root transform:

$$\arcsin(p)^{\frac{1}{2}} \qquad (34)$$

This will be particularly useful when a substantial number of observations are less than 20% and/or greater than 80%.

9. APPLICATIONS FOR STOCK ASSESSMENT

One immediate application of trawl survey results of significance in exploratory surveys is the development of estimates of potential yield. Gulland (1975 and elsewhere) has suggested the use of the formula:

$$Y_{e} = c^{*} M_{o} B_{o} \qquad (35)$$

as an initial approximation where B_o is the unexploited standing stock, c is a constant

described below, M is the instantaneous rate of natural mortality and Y is the potential yield. The constant c is dependent on the form of the equilibrium relationship between yield and population size. For example, if the equilibrium relationship follows the asymmetrical model of Fox (1970), then c = 1/e or approximately 0.37 while if the symmetrical Schaefer model is appropriate, the value of c is one half. The more conservative estimate obtained under the Fox model will be preferable if there is uncertainty about the underlying model. Beddington and Cooke (1983) demonstrated that estimates based on the symmetrical model are almost invariably optimistic. More realistic results are possible based on a simple age-structured model (Beddington and Cooke, 1983) but information on growth rates and other population parameters are required and these may not be readily available in a developing fishery. Nevertheless, the results of Beddington and Cooke indicate that, in general, the more conservative approach should be followed in estimating potential yield. It should also be noted that we assume that the survey estimate is taken from a population in equilibrium - if the population is at a high level due to chance fluctuations in recruitment, we run the risk of overestimating the potential yield. In general, consideration of stockastic recruitment patterns again indicates the desirability of conservative estimates of potential yield.

If the survey has been conducted on a virgin stock, survey estimates can be used to estimate potential yield. In terms of the estimators developed here for a simple random sampling design we simply substitute the population total for an unexploited population for B_o. If we assume that natural mortality is constant, the variance of Y is simply:

$$v(Y_e) = c^{*2} M^2 v(B_o) \tag{36}$$

where $v(B_o)$ is the estimated variance given by Eq. (7) for the population total (Y). If natural mortality is not known with certainty but assumed to be represented by some mean value M and variance V(M), then the variance of potential yield is:

$$v(Y_e) = Y_e^2 \left[\frac{v(M)}{M^2} + \frac{v(B_o)}{B_o^2} + \frac{2\,COV(M\,B_o)}{M\,B_o}\right] \tag{37}$$

where cov(M,Y) is the covariance of M and Y. Thus an estimate of the precision of the estimate of potential yield can be specified which is a function of the precision of the survey results. If the original survey design is a stratified random design, then the appropriate estimator for the mean and variance are used in Equations (10) and (11).

Survey results may also be useful in the context of surplus production models if information on catch and effort from the commercial fishery is not available. The form of a generalized production model (Pella and Tomlinson, 1969) is:

$$\frac{dB}{dt} = aB = bB^m - FB \tag{38}$$

where B is the population size; a,b and m are model parameters and F is the instantaneous rate of fishing mortality. Typically, catch-effort data are used to estimate parameters of the model. However, since the survey provides an estimate of population size, it is possible to substitute survey estimates into Eq. (37) to estimate model parameters. If B_t is the estimate of total abundance from the survey in year t derived from either SRS as in Eq. (6) or from stratified random sampling as in Eq. (10), and if estimates of fishing mortality are available, then we have as an approximation to Eq. (37):

$$B_{t+1} - B_t = aB_t - bB_t^m - F_t B_t \tag{39}$$

which can be solved by non-linear regression. If the shape parameter (m) is set to some arbitrary value, linear regression may be used. A value of m=2 will of course give a symmetrical Schaefer model. An estimate of maximum equilibrium yield is then:

$$MEY = a(a/mb)^{1/m} - b(a/mb)^{m/m-1} \tag{40}$$

Unfortunately, estimates of fishing mortality (F) may not be readily available. If the total catch of the species is known but fishing effort is not available, survey results can be used to generate an estimate of "relative effort". The relative effort index is defined as the catch divided by the survey catch per tow index:

$$f^* = C/\bar{y} \qquad (41)$$

where C is the commercial catch and y is the mean catch per tow. The relative effort index f* is essentially the equivalent effort that would be expended by the commercial fleet if it had the same fishing power of the survey vessel. We now rearrange Eq. (40) and substitute the term qf* for F. The new form is:

$$\log_e(B_{t+1}/B_t) = a - bB_t^{m-1} - qf^* \qquad (42)$$

where q is the survey catchability coefficient. The maximum equilibrium yield is estimated as before. Note that there is a disadvantage in using this simple regression model in that there is some degree of confounding of the dependent and independent variables. This should not present a major difficulty if our purpose is to provide a preliminary estimate.

The use of survey data in this context will have the distinct advantage that the fishing power of the survey vessel should have remained constant. The estimate of relative effort derived from resource surveys should therefore not be subject to the same types of bias that are common in the use of effort data from the commercial fishery.

Another obvious use of survey results is the development of an index of recruitment. Presumably if the trawl has been equipped with a small mesh cod-end to retain small individuals, and juveniles are accessible to the gear, a properly designed survey can provide an index of recruitment. Note that timing of the survey may be critical for recruitment estimates. Clark (1979) cites several applications of trawl survey results for this purpose. Typically, an empirical relationship between the survey recruitment index and an index of recruitment from the commercial fishery is developed based on regression methods and used for forecasting. In this case, and for developing total population estimates, the survey can only be of value if operational procedures, gear and vessels remain standardized and if the survey is conducted consistently over several years. In contrast, a single comprehensive survey may be sufficient to provide an estimate of potential yield using Eq. (35) (subject to the constraints mentioned previously).

In addition to the use of abundance estimates for stock assessment purposes, it is also possible to derive estimates of population parameters from size composition data. For example, Beverton and Holt (1957) provide the following estimator for total mortality:

$$Z = k(L_\infty - \bar{l})/(\bar{l} - l_c) \qquad (43)$$

where k and L_∞ are parameters from the von Bertalannfy growth equation, l_c is the size at first capture in the commercial fishery and $\bar{l}$ is the average length in the fishery. If the mean length in the fishery are not available, it may be possible to estimate Z from survey results under certain assumptions. If the survey vessel uses the same gear as the commercial fishery, $\bar{l}$ may be estimated from survey data and l_c can be obtained by inspection of the catch of commercial vessels. Note that the survey typically is concentrated during one (brief) time period and if mean length varies throughout the year as a result of recruitment and mortality, the survey estimate of $\bar{l}$ will not be representative of events in the fishery and this estimator cannot be used. Also, if the net used for the survey differs in selectivity from those in the commercial (for example due to a cod-end liner to retain small fish or due to much longer hauls) then further adjustments will have to be made in the survey size composition estimates to mimic the selectivity of commercial trawls.

Hoenig et al. (in prep.) provided an alternative estimator for total mortality based on size composition data:

$$Z = k \log_e 2/(\tilde{y}_m - y_c) \qquad (44)$$

where $Y_c = -\log (1-l_c/L_\infty)$ and where $\tilde{Y}_m$ is the median length. Again, the estimator should be based on the commercial fishery landings, however, survey results may provide useful information if some of the conditions described above hold.

10. ADRIATIC SEA SURVEY

An evaluation was made of the design of a trawl survey program conducted in the northern Adriatic region by personnel of the Laboratorio de Biologia Marina e Pesca, Fano, Italy, in cooperation with Yugoslavian scientists, aboard a chartered fishing vessel, the F/V Pipeta. The original design of the survey specified a series of 9 transects from the Italian to the Yugoslavian coast. A map of the survey region and location of the stations is given in Figure 3. A pair of replicate tows was made at each station, ranging from 1-1.5 hr in duration. A commercial style net was used during trawling operations.

A comparison was made between the precision of survey estimates for several commercially important species based on the original survey design (treated as a two dimensional systematic sample) and post-stratified survey estimates. Detailed sediment and bathymetric data were available for the survey area, providing the basis for development of stratum boundaries. An extensive history of biological research in the region was available to judge the suitability of the proposed strata for the species of primary interest. Previous trawling surveys (notably the R/V Hvar surveys during 1948-49) have been conducted in the region, contributing considerable information on the distribution and relative abundance of many of the fish species of commercial importance. It should be noted that the fisheries in the region exploit a multispecies complex of approximately forty species of fish and invertebrates and therefore it is unlikely that any one stratification scheme would be optimal for all species. Preliminary work on multispecies associations in the region, however, may provide sufficient information to develop allocation schemes for assemblages of species rather than trying to develop sampling strategies on a species by species basis. It should also be stressed that the replicate samples collected at each station were a notable feature of the systematic sampling design used in this series of surveys and therefore it is possible to provide an estimate of measurement error.

The strata employed in the analysis are depicted in Figure 3 and information on area, depth and substratum type of the seven strata are provided in Table 2. For the purposes of the present analysis, the mean of the two replicate samples collected at each station was used. The variance of the systematic sample was calculated under the assumption of a random distribution of organisms. The rationale for this approach is provided below. It should be noted that in the post-stratified analysis, stations were treated as if they were randomly chosen, possibly resulting in some degree of bias.

Estimates of the mean and variance of the mean for the systematic and post-stratified designs for two commercially important species, Mullus barbatus and Merluccius merluccius and for the total species complex are provided in Table 3. The post-stratified estimates of variance include the additional variance term attributable to the non-proportional allocation of stations in the post-stratified design. The stratification resulted in clear increases in precision for mullet, hake and the total species complex, suggesting that the adoption of a stratified random sampling design would be advantageous for determination of abundance indices for the species examined here. Further analysis of the usefulness of stratification for other species of commercial importance is being made by personnel of the Laboratorio di Biologia Marina e Pesca. It is possible that the stratification scheme examined would not prove useful for all species and that alternative stratification approaches would be necessary.

Acknowledgements

I would like to express my appreciation to S.Clark, S. Garcia, M. Pennington, and M. Sissenwine for their helpful criticism of this paper. I am grateful to D. Levi and C. Piccinetti for their assistance during my stay and to M. Rizzoli, E. Arneri, and O.Giovanardi for their help in analyzing the F/V Pipeta survey data.

11. REFERENCES

Abramson, N.J., (1968) A probability sea sampling plan for estimating relative abundance of ocean shrimp. Calif. Fish. and Game 54: 257-269.

Alverson, D.L. (ed.), (1971) Manual of methods for fisheries resource survey and appraisal. Part 1. Survey and charting of fisheries resources. FAO Fish. Tech.Paper 102: 80 p.

Beddington, J.R. and J.G. Cooke., (1983) The potential yield of fish stocks. FAO Fish.Tech.Paper 242: 47pp.

Bellhouse, D.R., (1977) Some optimal designs for sampling in two dimensions, Biometrika 64:605-11.

Beverton, R.J.H. and S.J. Holt., (1957) On the dynamics of exploited fish populations. U.K. Min. Agri.Fish., Fish. Invest. (Ser. 2) 19: 533 pp.

Clark, S.H. and B.E. Brown., (1977) Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-1974, as determined from research vessel survey data. Fish.Bull. NOAA/NMFS,75(1):1-25

Clark, S.H., (1979) Application of bottom-trawl survey data to fish stock assessment. Fisheries 4:9-15.

Cochran, W.G., (1977) Sampling techniques, New York, Wiley and Sons, 422 p. 3rd ed.

Das, A.C., (1950) Two dimensional systematic sampling and the associated stratified and random sampling. Sankhya 10:95-108.

Doubleday, W.G., (1981) Manual on groundfish surveys in the NAFO area (revised). NAFO SCS Doc. 81/VI/7: 77 p.

Edwards, R.L., (1968) Fishery resources of the Atlantic area. (In) D. Gilbert, (Ed.), The future of the fishing industry of the United States, pp.52-60, Univ.Wash.Publ.Fish., new Ser., 4.

Elliot, J.M, (1970) Some methods for the statistical analysis of samples of benthic invertebrates. Freshw. Biol. Assoc. Sci.Pub. 25: 148 p.

Fox, W.W., Jr., (1970) An exponential surplus yield model for optimizing exploited fish populations. Trans.Am.Fish.Soc.99:80-88.

Grosslein, M.D., (1969) Groundfish survey program of BCF Woods Hole. Commer.Fish.Rev. 31(8-9): 22-30.

Grosslein, M.D. and A. Laurec, (1982) Bottom trawl surveys design, operation analysis. CECAF/ ECAF series 81/22: 25p.

Gulland, J.A., (1975) Manual of methods for fisheries resource survey and appraisal. Part 5. Objectives and basic methods. FAO Fish.Tech.Pap. 145: 29p.

Hansen, M.H., W.N. Hurwitz, and W.G. Madow, (1953) Sample survey methods and theory. John Wiley and Sons, New York. Vol.I.

Kish, L., (1965) Survey sampling. John Wiley and Sons, New York. 643 pp.

Lenarz, W.H. and P.B. Adams, (1980) Some statistical considerations of the design of trawl surveys for rockfish (Scorpaenidae). Fish.Bull. NOAA/NMFS 78: 659-674

Mackett, D.J., (1973) Manual of methods for fisheries resource survey and appraisal. Part 3. Standard methods and techniques for demersal fisheries resource surveys. FAO Fish.Tech.Paper 124: 39 p.

Pauly, D., (1979) Theory and management of tropical multispecies stocks: a review, with emphasis on the Southeast Asian demersal fisheries. ICLARM Stud. and Rev. No. 1 Int. Cent. Living Aquat. Res.Mgt., Manila: 35 p.

Pella, J.S., and P.K. Tomlinson. (1969) A generalized stock-production model. Bull.Inter-Amer.Trop. Tuna Comm. 13: 421-496.

Pennington, M., (1983) Efficient estimators of abundance, for fish and plankton surveys. Biometrics. 39: 281-286.

Pielou, E.C. (1977) Mathematical Ecology. John Wiley and Sons, New York, 385 p.

Quenouille, M.H. (1949) Problems in plane sampling. Ann.Math. Statist. 28: 355-375.

Saville, A. (Ed.). (1977) Survey methods of appraising fishery resources. FAO Fish.Tech.Paper 171: 76 pp.

Sissenwine, M.P., T.R. Azarovitz, and J.B. Suomala. (1983) Determining the abundance of fish. In: Experimental biology at sea, edited by A. MacDonald, London, Academic Press, Inc., Chapter 3.

Sukhatme, P.V. and Sukhatme, B.V. (1970) Sampling Theory of Surveys with Applications. FAO, second edition.

Taylor, C.C. (1953) Nature of variability in trawl catches. Fish.Bull. USFWS 54: 145-166.

Troadec, J.P. (1980) Utilization of resource survey results in stock assessment. FAO/TF/INT 80 (c) (CAN) Suppl.: 139-152.

Ulltang, O. (1977) Methods of measuring stock abundance other than by the use of commercial catch and effort data. FAO Fish.Tech.Paper 176: 23 p.

Table 1

Hypothetical list of sampling objectives for two types of survey (i) an exploratory survey and (ii) a long-term monitoring survey. Objectives are listed in hypothetical order of priority.

SURVEY TYPE	OBJECTIVES
EXPLORATORY	DETERMINE TOTAL ABUNDANCE
	ESTIMATE POTENTIAL YIELD
	DETERMINE SPATIAL DISTRIBUTION
	ESTIMATE POTENTIAL COMMERCIAL CPUE
LONG-TERM	DETERMINE TRENDS IN ABUNDANCE
	PROVIDE RECRUITMENT INDEX
	ESTIMATE SIZE COMPOSITION
	ESTIMATE AGE COMPOSITION
	DETERMINE FEEDING PREFERENCES
	COLLECT MATURITY DATA
	DETERMINE INCIDENCE OF DISEASE

Table 2

Stratum definitions and characteristics for post-stratification of survey region in the northern Adriatic Sea. Surveys conducted by personnel of the Laboratorio di Biologia Marina e Pesca, Fano, Italy, in cooperation with Yugoslavian scientists.

STRATUM NO.	SUBSTRATE TYPE	DEPTH (m)	AREA (sq.km)
1	MUD	<50	12 126
2	MUD	>50	5 681
3	SAND	<100	19 365
4	SAND-MUD	>100	16 311
5	MUD	>200	1 390
6	SAND	>50	8 490
7	MUD	>100	7 400

Table 3

Estimates of mean density and its variance based on systematic sampling and post-stratified sampling for Mullus barbatus, Merluccius merluccius, and for the total species complex.

SPECIES	SYSTEMATIC		POST-STRATIFIED	
	Mean	Variance	Mean	Variance
Mullus barbatus	0.509	0.324	0.464	0.207
Merluccius merluccius	0.846	0.426	1.003	0.247
Total Species	3.048	.276	3.117	0.232

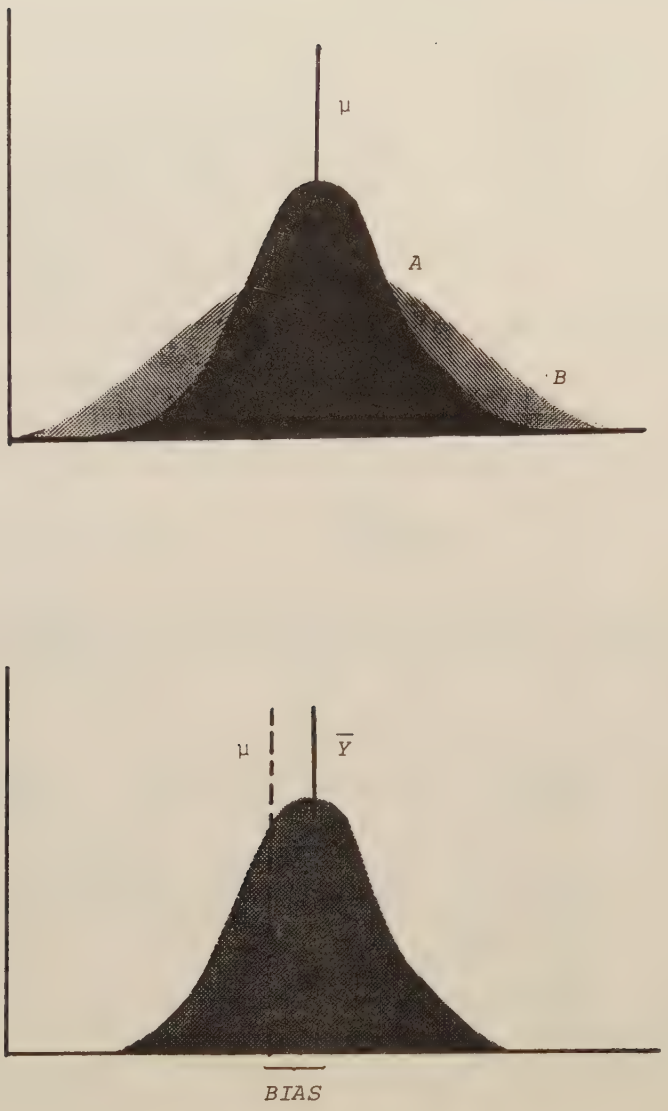

Figure 1. Representation of concepts of precision and bias in an estimator. In the upper panel, curve A represents the variability about an estimator of the true population mean which is more precise than that represented by curve B under a less precise estimator. Both estimators are unbiased. In the lower panel, the difference between an estimate of the mean and the true population value is shown.

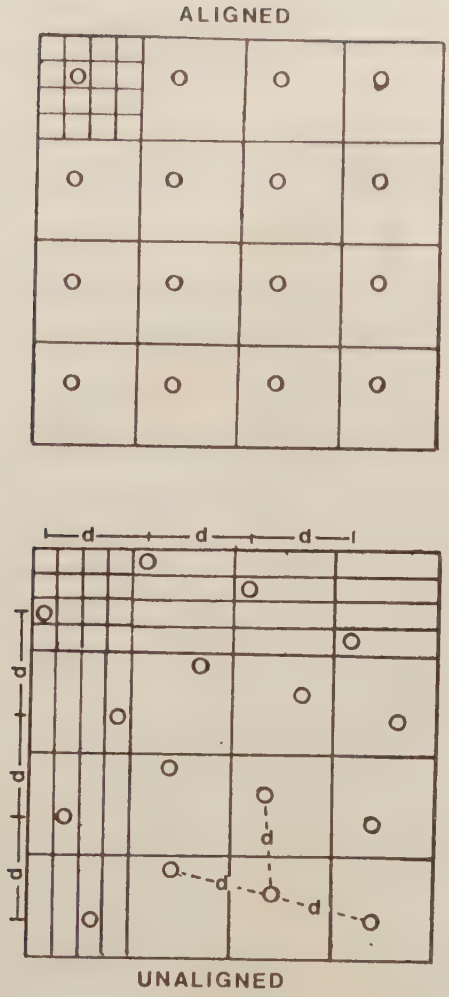

Figure 2. Illustration of two types of systematic sampling designs, an aligned sample and an unaligned sample. See text for description of methods used in choosing the sample.

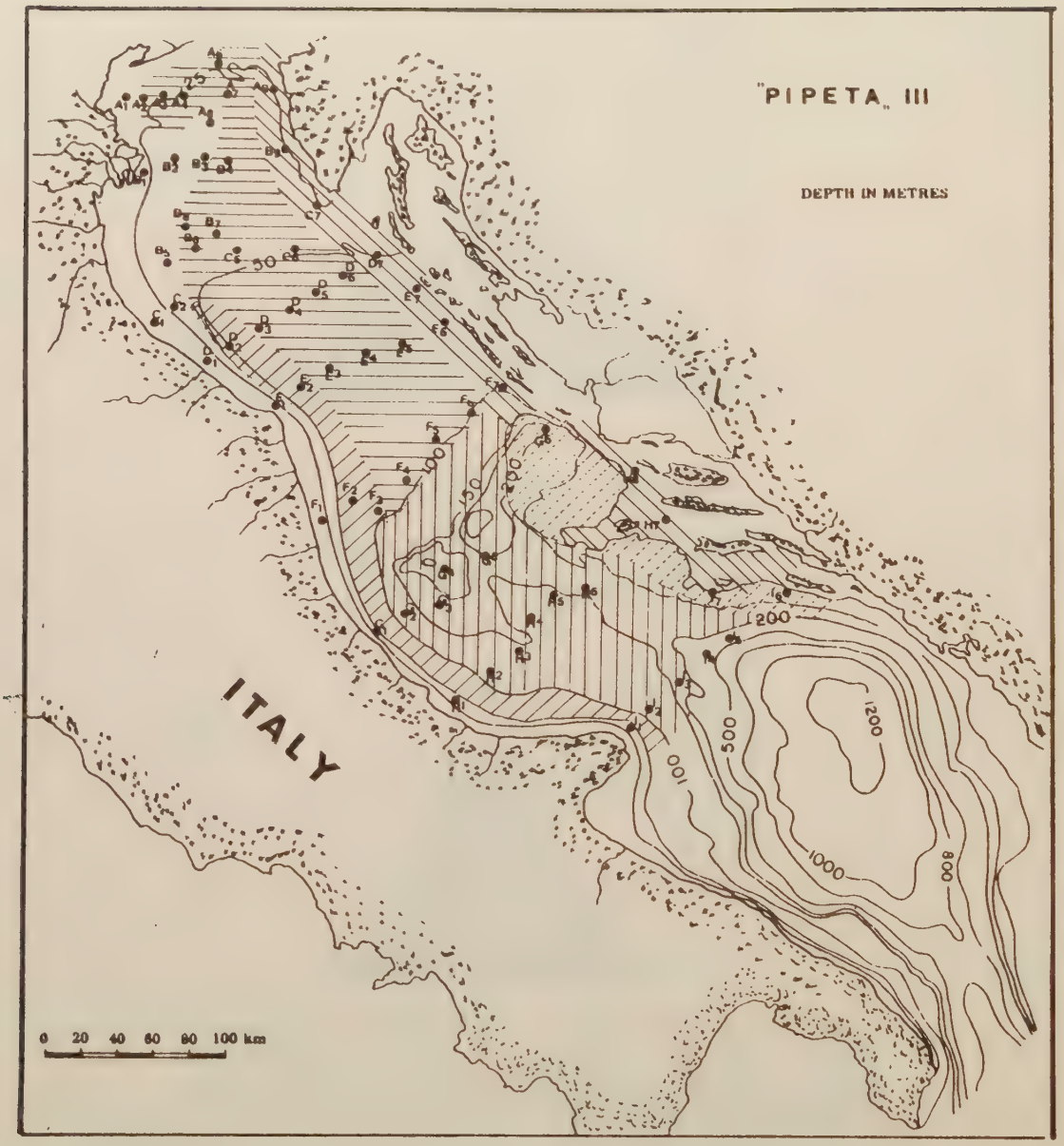

Figure 3. Map of survey area in northern Adriatic Sea showing location of sampling sites under a systematic sampling design. The location of proposed stratum boundaries is also shown.

14. APPENDIX A

In this section , the term G_m used in the transformation described in Eq 31 is provided. The expression is:

$$G_m = 1+\frac{n-1}{n}\,t + \sum_{j=2}^{\infty} \frac{(n-1)^{2j-1}}{n^j (n+1)(n+3)\ldots(n+2j-3)} \cdot \frac{t^j}{j!}$$

This expression is an infinite series and is difficult to deal with without computer facilities. A simple algorithm in BASIC which is suitable for use on a microcomputer is :

```
100 INPUT T,N:J=2:S+(N-1)↑3/(N↑2*(N+1)))*T↑2/2:A=1+(((N-1)/N)*T)+S
110 J=J+1 : S+S*((N-1)↑2/((N*(N+2*J-3))*J))*T:A=A+S:IFS< .000001 GOTO110
120 PRINT INT(A*1000+.5)/10000:END
```